

MIPP (E907) TPC

Electrical Description

Abstract

The MIPP Experiment (Fermilab E907) uses a 2 m³ time projection chamber (TPC). This note describes the TPC electrical systems (low voltage, high voltage, and grounding), the custom boards (sticks and receiver cards) and the electrical installation in the experiment beam area, MC7.

Responsible Individuals

Peter Barnes 925-422-3384 510-610-0366 (cell) pd Barnes@llnl.gov	Rajendran Raja 630-840-4092 raja@fnal.gov
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Contents

- [Introduction](#)
- [Subsystems Overview](#)
- [Chamber](#)
- [Front End Cards \(Sticks\)](#)
- [Low Voltage Power Supplies](#)
- [Low Voltage Rack Protection and Interlock System](#)
 - [Rack AC Power Interlock](#)
 - [DC Master Interlock](#)
 - [Air Flow Rack Interlock](#)
 - [Stick DC Interlock](#)
 - [Interlock Summary](#)
- [High Voltage Systems](#)
 - [Cathode High Voltage](#)
 - [Anode High Voltage](#)
- [Grounding](#)
- [VME Digital Receiver Cards](#)

Introduction

The MIPP Experiment (Fermilab E907) is a fixed target experiment in the Meson Center Enclosure 7 (MC7) beam line of the Meson Area at [Fermilab](#). It will use 120 GeV/c Main Injector beam and will measure particle production from primary beam interactions in the NuMI/MINOS target, and from secondary beams interacting with thin targets. One of the main detectors is a 2 m³ time projection chamber (TPC), operated with P10 gas, a -10 kV drift potential, and +1300 V anode potential for gas gain of the ionization signal. The

TPC uses custom readout electronics and VME interface to commercial data acquisition processors.

The TPC was built *circa* 1990 by [LBL](#) for the [EOS](#) experiment at the Bevalac. It was subsequently used by [E910](#) and [E895](#) at [BNL](#), and last operated there in 1997. Reusing an “old” detector introduces two kinds of challenges not present in a new design. First, retrieving and capturing the original design knowledge from 10 years ago (nearly pre-Internet) has been non-trivial. Second, the TPC relies on two custom multi-layer printed circuit designs, and a semi-custom bulk power supply system. These were designed and built in a different era, and likely would be done somewhat differently today. Mitigating against these difficulties is the experience base operating these systems over a seven year period at two other laboratories.

In this note we describe the TPC electrical systems, including racks, power distribution, cabling, and interlocks, as they are configured in MC7. (The mechanical support structures and gas system are described elsewhere.)

We start with a brief description of the TPC itself and the supporting systems. We then discuss each system in detail, including the racks, crates, power, and cabling for each system.

Subsystems Overview

The TPC detector has a number of subsystems: the chamber itself, front-end electronics, DC power and interlock, digital readout, high voltage systems, the gas system, and mechanical support. The gas system and mechanical support are beyond the scope of this note.

[Figure 1](#) shows the floor layout of TPC components in MC7. [Figure 2](#) shows a photograph of the TPC. [Figure 3](#) shows an exploded view of the chamber with the outer case, which forms the gas envelope, removed.

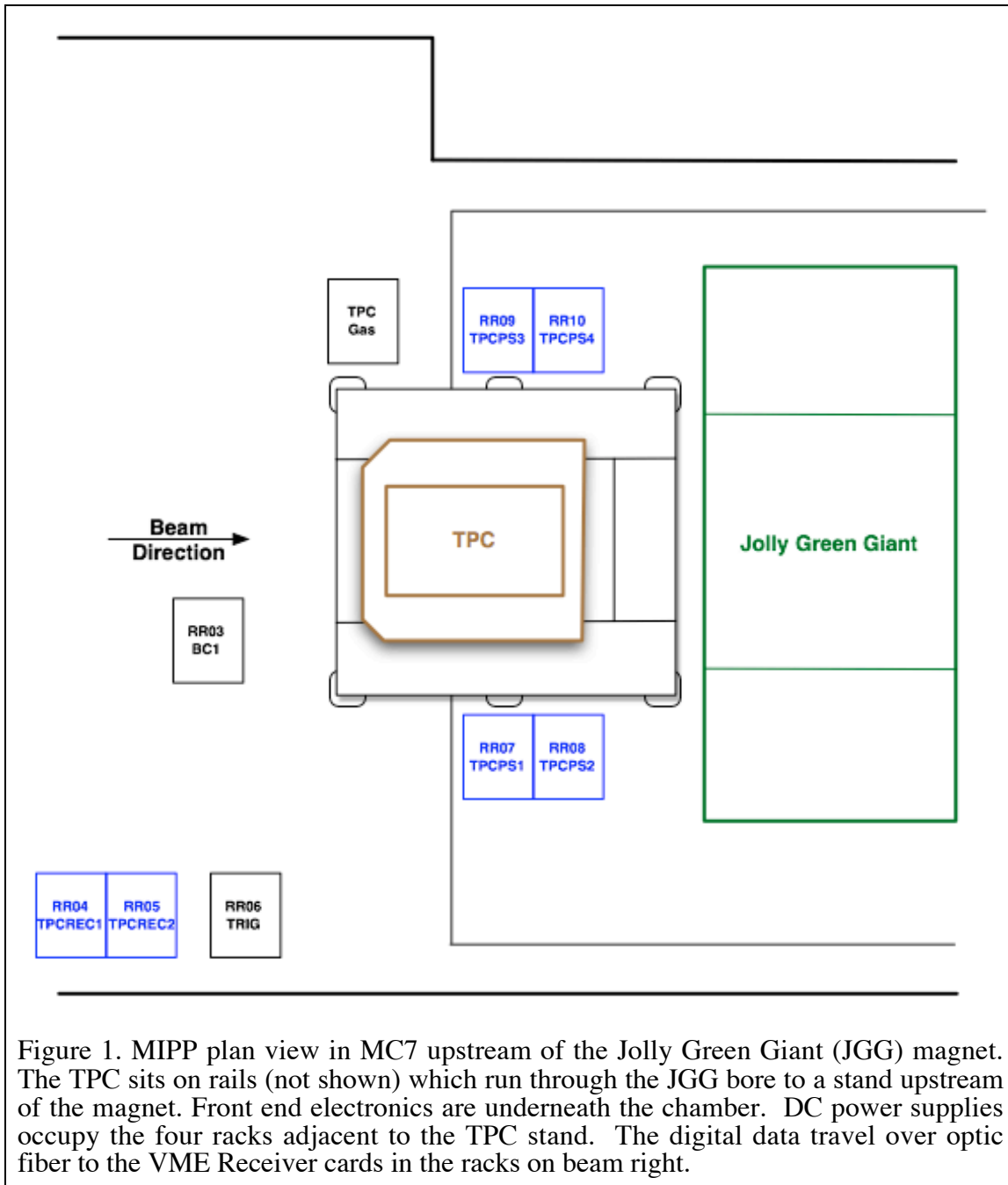


Figure 1. MIPP plan view in MC7 upstream of the Jolly Green Giant (JGG) magnet. The TPC sits on rails (not shown) which run through the JGG bore to a stand upstream of the magnet. Front end electronics are underneath the chamber. DC power supplies occupy the four racks adjacent to the TPC stand. The digital data travel over optic fiber to the VME Receiver cards in the racks on beam right.

The TPC itself rests on a stainless steel cart, which rolls on stainless steel rails into the Jolly Green Giant (JGG) magnet bore. The rails are in turn supported by an aluminum stand/table upstream of the JGG magnet. The mechanical support system engineering is beyond the scope of this note.

The TPC front-end electronics reside underneath the chamber (see [Figure 2](#)). The DC power supplies occupy the four racks (RR07–RR10) adjacent to the stand. The digital readout boards reside in VME crates in RR04 and RR05. These racks also house the cathode and anode high voltage supplies.



Figure 2. Picture of the TPC. The front 30 cm contains an optics bench (originally for a laser calibration system not used in MIPP) and the target changer. The large box behind the laser bench contains the active volume and sits on the water-cooled front end electronics enclosure. In the picture, the person is leaning over the outer end of the electronic bay, which houses the front end cards. The blue plastic tubing is part of the water cooling manifold.

Briefly, the chamber operates as follows: Charged particles passing through the active volume leave an ionization trail. The electrons drift down under the influence of a uniform electric field set up by the cathode plane and ground wire array (see [Figure 4](#)). The electrons pass through the ground array and are accelerated into anode wires. The electron–gas scattering that occurs in the high field region around the anode wires causes additional ionization, yielding gas gain. The ionization induces image charges in the pads, which are amplified and digitized by the front end “sticks” residing in an electronics bay under the chamber. The digital data are transferred to VME “receiver” cards and processors by fiber optic cables.

The P10 gas is supplied by a modest gas system. The system allows flow with either nitrogen or pre-mixed P10, at either purge or operating flow rates (6 or 1 λ /min, respectively), and contains vent and overpressure relief bubblers. The gas rack is grounded separately from the TPC. The electronics bay is purged with nitrogen. The gas system engineering is beyond the scope of this note.

The front end sticks are powered by a bulk DC power supply system. The DC supply contains a master interlock that requires sufficient cooling water flow, water temperature within range, and the presence of the clock (to protect one of the chips on the sticks). In addition, each of the four racks are separately interlocked to their own cooling air flow, and each output channel (all supplies for one stick) are interlocked for proper card insertion in the electronic bay, card temperature, and power supply voltage. Finally, the four DC racks are protected by AC power controllers enabled by a smoke detector daisy chain.

The fiber optic receiver cards and VME processors are located in crates in the digital racks. The cathode and anode voltages are supplied by high voltage power supplies also located in the digital racks.

We describe each of the sub-systems in the following sections.

Chamber

In this section we briefly describe the chamber, its internals (see [Figure 3](#) and [Figure 4](#)), and the operating voltages. We describe the on-chamber connectors with the associated electronics in the following sections.

The chamber itself consists of three main volumes:

- The front-end stick electronics bays in the pad plane support structure,
- The gas volume defined by the chamber frame with the thin side walls and thick lid, and
- The optics bay for the old laser calibration system.

All structural materials are aluminum. The pad plane itself is NEMA G-10 (FR-4 is unsuitable in this application because it poisons the drift gas). The gas volume side walls are thin aluminum sheets, to minimize scatter for the exiting particles, while the lid is a thick (1/4") aluminum plate. The side walls and lid are sealed by O-rings. Finally, the upstream face of the chamber has a re-entrant mylar window, to allow the target to come as close as possible to the field cage and active volume.

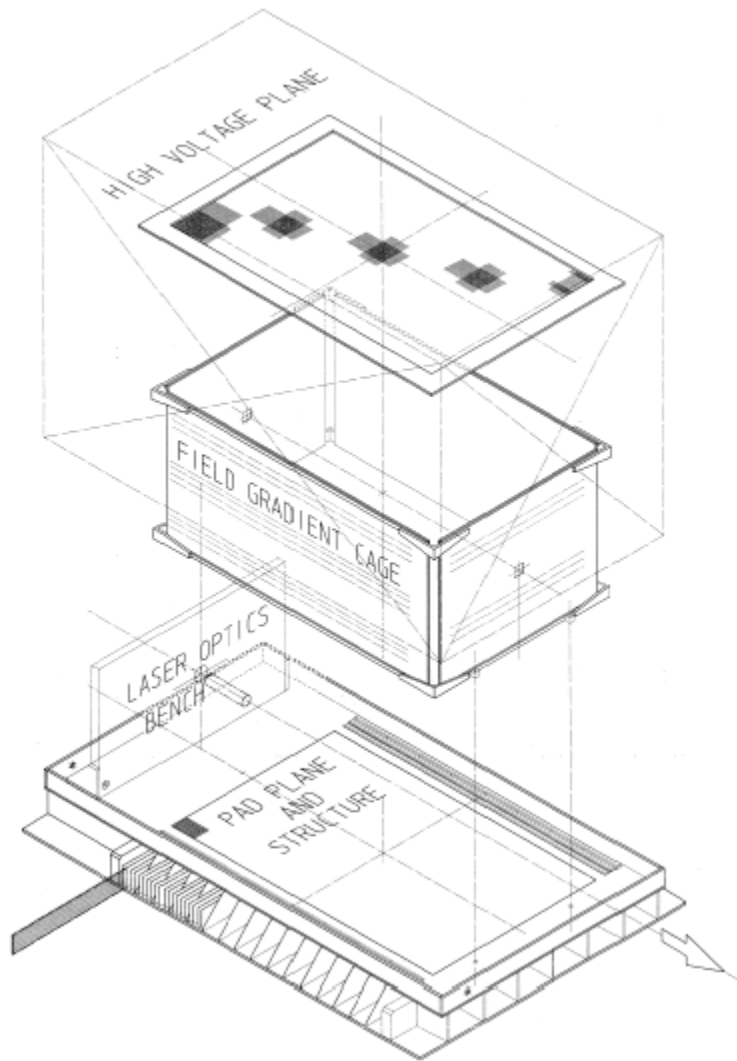
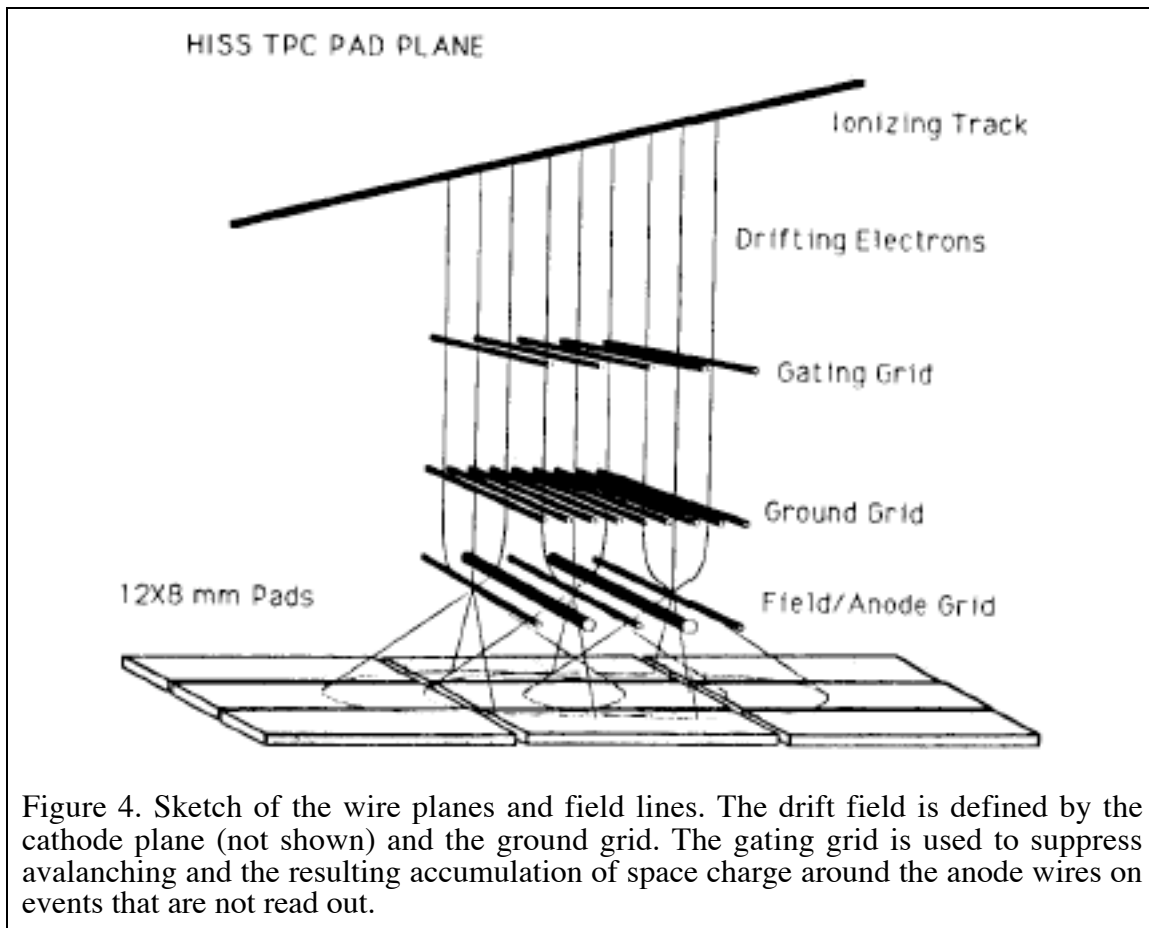


Figure 3. Exploded view of the TPC with the outer case removed. The active volume is defined by the pad plane, field cage, and high voltage (cathode) plane.



The high voltage plane (cathode) operates at 10 KV, powered by a single supply. The field gradient cage consists of circumferential copper strips, connected by a resistive divider network. A ground wire plane, just above the pad plane, defines the other side of the drift region. The combination of the cathode, field cage, and ground wire plane defines a uniform drift field in the active volume.

The anode wires operate at up to 1300 V, powered by 16 independent channels of a HV power supply crate.

Front End Cards (Sticks)

The 128 front-end cards, known as “sticks,” sit in the electronics bay just below the pad plane. See [E907 TPC Front End Electronics "Stick"](#) for pictures. A partial schematic set is available on the [LBL Drawings](#) page. The on-board power and interlock connections are shown in [Figure 5](#). Spare cards are available for inspection.

The sticks are constructed of two multi-layer boards mounted on a thin aluminum wedge. When installed, the base of the wedge is in contact with the bottom of the electronics bay, which is water-cooled. This is the primary cooling for the sticks.

The electronics bay is purged with nitrogen. The exhaust passes a smoke detector on the AC interlock loop (described below).

The sticks connect to the pad plane structure through a zero-insertion-force card edge connector (essentially an [AMP Linear ZIF Connector](#)). The pad plane and ZIF connector, in addition to connecting the pads to the sticks, encode the stick slot position and form an interlock for proper card insertion. If the card is not completely inserted, the interlock contacts are not made up, and the DC power supply interlock will not make up for that stick, preventing power from being applied to the board. The sticks also contain a thermal limit switch, set to open at 40°C, in the interlock chain.

The sticks are supplied ± 15 V, ± 5 V, and +6 V DC power through a 17-pin Molex connector (see [Figure 5](#)). In addition, each stick receives two 10-pin ribbon cables, one for the slow control BitBus interface, the other for clock and trigger distribution. Finally, the digitized data are pushed out onto optical fiber.

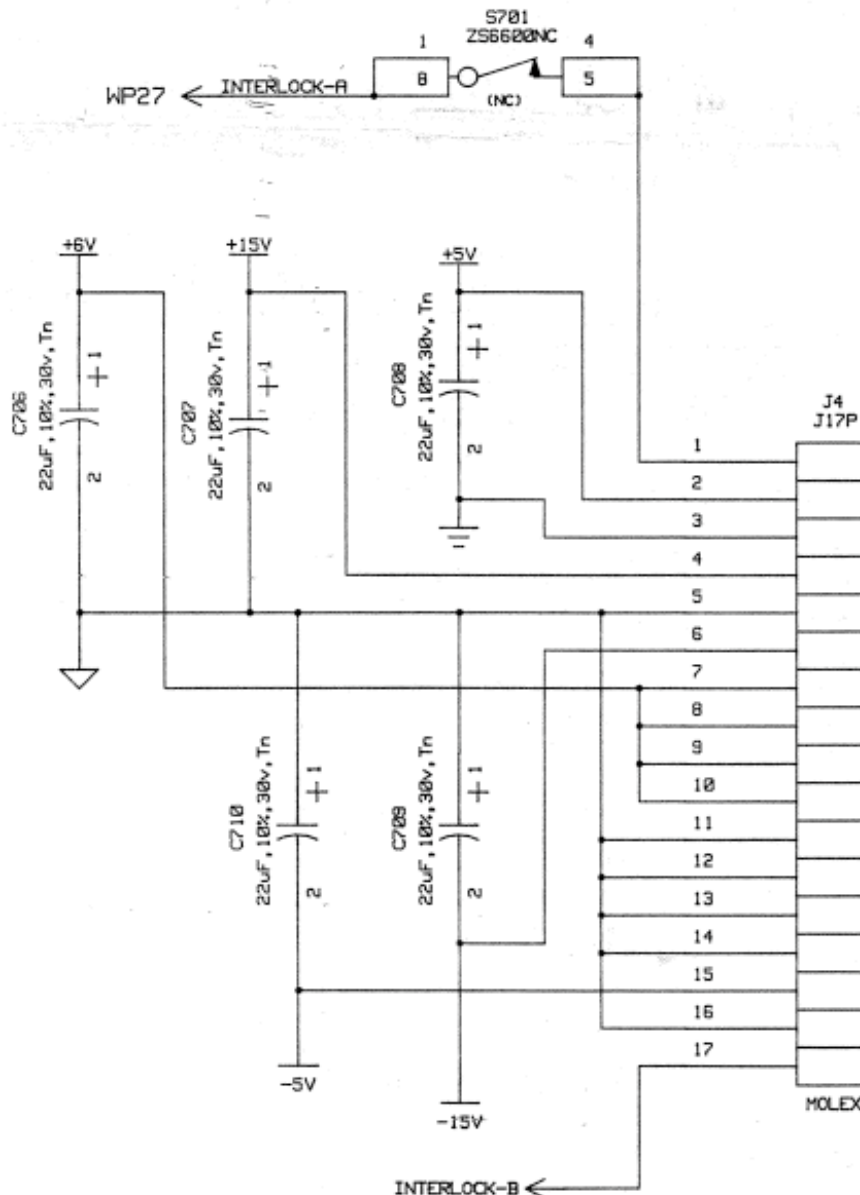


Figure 5. Power supply input circuit to the front end sticks, taken from the LBL drawing [14V8754 S1, "READOUT BOARD TAXI CONTROL LOGIC, SIDE B"](#). After passing through a temperature switch at the inboard end of the stick, the "INTERLOCK-A" line crosses from the "B" side to the "A" side at pin "WP27." When the card is fully inserted into the chamber, the chamber connects this line to "INTERLOCK-B" back on the "B" side, thereby completing the on-board interlock loop.

Low Voltage Power Supplies

The bulk low voltage DC power supplies are located in the four racks RR07–RR10, two on each side of the chamber. See [EOS TPC Low Voltage Racks](#) for pictures and chassis

identification information (some chasses have been relocated within the racks since these pictures were taken). These racks also contain AC, DC, and rack interlocks.

The [Low Voltage Power Supply Chassis](#) circuit diagram is available on the [LBL Drawings](#) page. Each chassis contains four independent channels; each channel supplies all voltages (± 15 V, ± 5 V, and $+6$ V DC) for one stick.

Each channel consists of two commercial open frame linear power supplies ([Conдор Inc.](#)), as shown in the following table.

Model	Output 1 (Max)	Output 2 (Max)
HBAA-40WA	5V @ 3 A (used as $+6$ V)	± 15 V @ 0.8 A
HAA5-1.5/OVPA	± 5 V @ 1.5 A	

The supplies are over-voltage and over-current protected. No remote sensing is used. The supply grounds are decoupled from the power supply chassis by 100 K resistors. The sticks provide low impedance ground through the chamber ground.

Each channel contains a separate AC circuit breaker, an interlock-controlled relay on the AC line, and a voltage monitor output (not used). The interlock requires the rack airflow interlock, the stick interlock, and proper supply voltages, in order to energize the channel. Figure 6 shows a simplified schematic for the interlock chain.

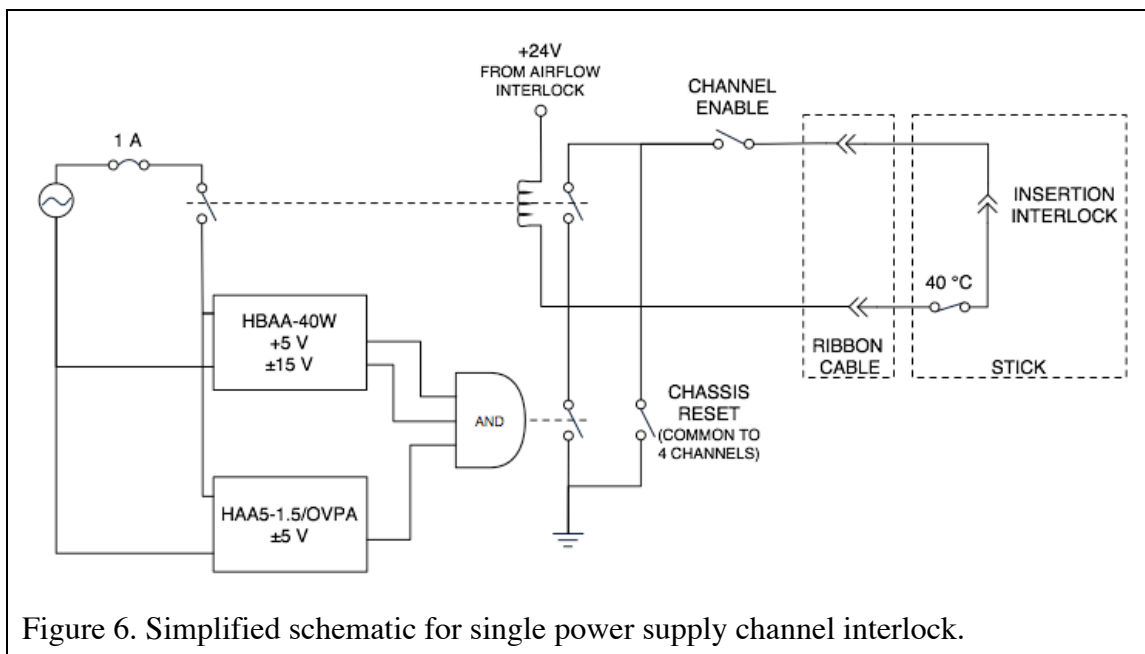


Figure 6. Simplified schematic for single power supply channel interlock.

The DC power (and the stick interlock loop) is delivered to the sticks through a 17-conductor ribbon cable of 20 AWG conductors, 15 m long, one cable per stick. The ribbon cable uses a Molex 09-50-8173 connector, rated for 4.75 A per contact. The supply currents are carried each on a single conductor (see Figure 5), except for the $+6$ V, which uses four conductors, and the ± 15 V, $+6$ V, and -5 V common returns, which uses six conductors, (The $+5$ V return is carried on a single conductor).

Low Voltage Rack Protection and Interlock System

The DC supplies and racks are interlocked at four levels: rack AC power system, DC power system, rack, and channel. See Figure 6 for a sketch of the relevant components.

Rack AC Power Interlock

Figure 7 shows the rack protection system. Each pair of racks has an AC power controller, which supplies power to all units (24V supplies, blowers, NIM bin, gating grid drivers) except the EOS power supplies. (The AC power for these supplies is controlled at the channel level.) The power controllers are enabled by a smoke detector chain, using a detector in each rack and on the electronics bay nitrogen purge exhaust.

In addition, the control panel has an ON/OFF switch in series with the interlock loop, and an INTERLOCK/OVERRIDE switch for operating the system with a tripped smoke detector to discover the source of the fault.

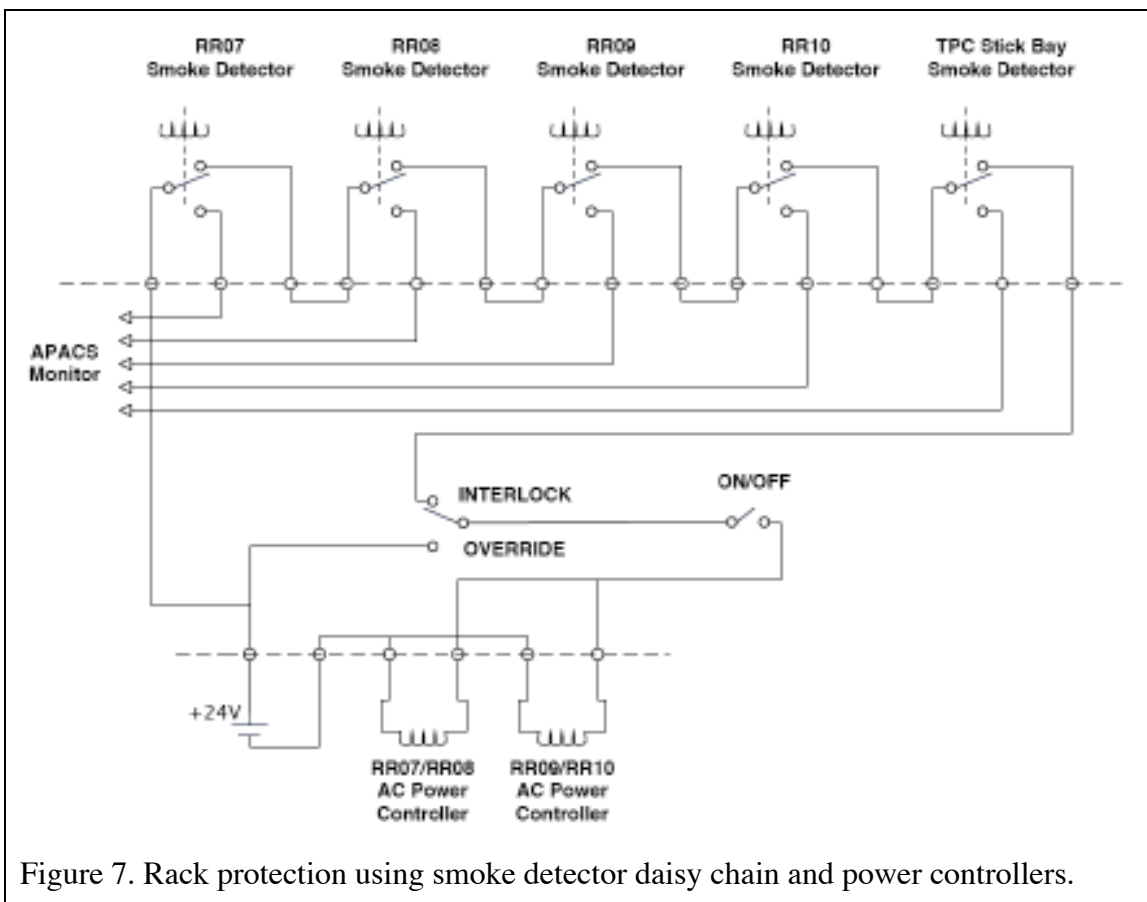


Figure 7. Rack protection using smoke detector daisy chain and power controllers.

The 24V power for this loop comes from the MIPP rack protection master supply, located near the upstream east door. The relay state is monitored by APACS, to identify the first detector in the chain that trips.

DC Master Interlock

All EOS DC Power Supplies are controlled by a relay on the AC input. These relays are in turn controlled by the DC Master Interlock system.

The DC Master Interlock ([LBL Drawing 14V8833 S7](#)) chassis is located near the bottom of RR07, just above the fan unit. It constructs the Master Interlock signal that enables each of the Air Flow Rack Interlock chassis. To enable the Master Interlock, the water interlock loop must make up, and the clock must be present. (The clock input is required because one of the chips on the sticks will latch up and overheat if DC power is applied without a clock present.). This chassis also implements the Air Flow Interlock functions for its rack.

A pair of 24V DC power supply chassis supply the control power for the EOS Master Interlock chassis, the EOS Air Flow Rack Interlock chassis in each of the other racks, and the EOS Power Supply control relays. These 24V supplies consist of one open frame linear power supply, [Kepco Model PRM24-12](#), supplying 24V at 12 A. Power is distributed through 16 AWG cable.

Air Flow Rack Interlock

The EOS Air Flow Rack Interlock chassis are located near the bottom of each rack, just above the fan units. These chassis impose the Master Interlock and rack airflow interlocks on the 24V control power to each of the power supply chassis in the same rack. The 24V control power is distributed via 22 AWG cable to each power supply chassis. The schematic for these units is identical to the upper left quadrant of the Master Interlock schematic ([LBL Drawing 14V8833 S7](#)).

Stick DC Interlock

The individual DC supply channel interlock is described above and shown in Figure 6. It requires that the stick be fully inserted into the chamber, that the stick temperature switch be less than 40 C, and that the stick not overload the supply voltages, causing them to sag.

Interlock Summary

The entire interlock system requires the following conditions:

1. Rack and TPC smoke detector relay chain makes up and AC Master INTERLOCK/OVERRIDE switch in INTERLOCK position,

–OR–

AC Master INTERLOCK/OVERRIDE in OVERRIDE position.

2. AC Master ON/OFF switch in the ON position.

These conditions turn on the following equipment:

- EOS 24V DC power supplies in RR07 and RR09.
- NIM bin in RR08, which contains the CLOCK.
- EOS Gating Grid Power Supplies in RR07.
- Blowers and fan packs in each rack.

3. Neslab Chiller water temperature within the Temperature Alarm High and Low set points (15 C and 25 C, respectively).
4. Water pump turned on and water flow meter above the low limit set point (10 gpm).
5. Clock signal is present at EOS Master Interlock chassis.

These conditions allow one to reset the CLOCK DROP and WATER DROP inputs to the EOS Master Interlock chassis.

6. EOS Air Flow Rack Interlock detects adequate airflow (one per rack).
7. EOS Power Supply channel is connected to stick, which is completely seated in the TPC ZIF connector slot and not over-temperature.
8. DC Power Supply channel front panel switch is in the `ENABLE` position.

If the preceding conditions have been met, the EOS Master Interlock chassis will indicate a trip in the corresponding rack:

Indicator	Rack
A	RR09
B	RR10
C	RR07
D	RR08

To clear this indication and energize the channel press any EOS Power Supply RESET button in the corresponding rack.

High Voltage Systems

Cathode High Voltage

The cathode plane high voltage is generated by a commercial supply, Bertan Model 225-20R, located at the bottom of RR04. This supply is capable of delivering up to 1 mA at up to 20 kV. We operate the supply manually from the front panel and remotely using a GPIB link. It is capable of both current and voltage limiting, however these must be set after power up, so these should be considered administratively implemented engineering controls.

Normal operation is 10 kV at 80 μ A, set by the resistive divider chain on the field cage. For ramping up the voltage by hand we have found that a current limit of 120 μ A is more reasonable to allow for transients during the ramp.

The voltage is delivered to the chamber by a 30 m green RG 213/U cable, run through the cable tray, with Reynolds 167- 3516 connectors at each end. Both the supply and chamber have the mating panel connector, Reynolds 167-3517. The chamber connector is at the upstream beam left (south west) corner.

Anode High Voltage

The anode wires are ganged, internally to the chamber, into 16 anode sections. Each section is supplied high voltage independently by a channel from the LeCroy 1440 High

Voltage crate, located at the bottom of RR05. The TPC uses two Model 1444P cards, which are capable of supplying 5.6 kV at up to 1 mA on eight channels per card. The cards can be programmed to trip on overcurrent. In past tests (with significant amounts of water vapor still present in the chamber) we have seen currents generally less than 1 μ A. This supply is remote controlled.

The voltage is delivered to the chamber by 30 m red RG 58 C/U cables in the cable tray with SHV connectors on each end. The chamber connectors are on the beam left (west) side.

Grounding

The chamber is grounded by a xx AWG wire, connected to a ground lug near the cathode input. This ground wire connects to RR04-RR05, which are in turn connected to MC7 ground.

The TPC Stand and Rails are grounded to the JGG magnet and concrete slab.

VME Digital Receiver Cards

The digitized data from the sticks are carried on optical fiber to the VME Receiver crates, in RR04 and RR05. These are commercial VME crates, split into a 6U and a 9U section. The 6U components (processor, BitBus interface, Interrupt interface) are commercial units. The 9U sections contain custom EOS Receiver cards.

The VME crates and receiver cards are protected by the MIPP rack protection system. A daisy of smoke detectors, one per rack, control the experiment AC power main breakers. Smoke detected in any rack interrupts the chain, turning off all experiment AC power. The state of each smoke detector is monitored by APACS, to identify the first detector in the chain that trips.